CONTRACTOR REPORT

PLANETARY AERONOMY

IV: THE DUOPLASMATRON AS A VACUUM ULTRAVIOLET LIGHT SOURCE

by J. A. R. Samson and H. J. Liebl

Prepared under Contract No. NASw-395 *by*
GEOPHYSICS CORPORATION OF AMERICA
Bedford, Massachusetts
for

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ABSTRACT

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A light source was investigated that would emit radiation below 1000 A of comparable intensity to the high-voltage pulsed type but which would operate from a d.c. supply. It was felt that with the combination of hot filament and axial magnetic field as found in the Duoplasmatron that the light intensity would be comparable with the high voltage pulsed light sources. A preliminary measurement of the total intensity between 1050 A and 1350 A was made using a nitric oxide ion chamber with a Duoplasmatron as an ion source. Spectrums are determined for hydrogen between 1800 A and 900 A and for argon from 550 A to 1100 A. Author

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THE DUOPLASMATRON AS A VACUUM ULTRAVIOLET LIGHT SOURCE*

I. INTRODUCTION

The Duoplasmatron was developed about twelve years ago as a highly efficient source of protons After its publication[1] in 1956, a number of variations were designed and used as ion or electron sources for such applications as accelerator ion sources and ion propulsion devices.[2,3,4] A further application was suggested by Herzog;[5] namely, that the highly concentrated plasma of a Duoplasmatron possibly would emit intense vacuum ultraviolet radiation.

In the spectral region below 1000 A conventional light sources are of the high voltage pulsed type with their inherent disadvantages that they radiate electrical noise and are difficult to operate at a constant light intensity output Thus, it is desirable to look for a light source which emits radiation below 1000 A of comparable intensity to the high voltage pulsed type but which operates from a D.C. supply. The hot filament type of light source falls into this category with the exception of light intensity It was felt, therefore, that with the combination of hot filament and axial magnetic field as found in the Duoplasmatron that the light intensity would be comparable with the high voltage pulsed light sources

*The content of this report has been submitted for publication to the "Review of Scientific Instruments."

A preliminary measurement of the total intensity between 1050 A and 1350 A was made using a nitric oxide ion chamber with a Duoplasmatron which was currently being used as an ion source. The source had an anode opening of 0.008 inches Using hydrogen in the Duoplasmatron with an arc current of 300 mA, a flux of approximately 10^{12} photons/sec/cm^2 was measured at a distance of 25 cm from the anode opening for the 1216 A Lyman-alpha line. This is based on the assumption that 50% of the ion chamber response was due to the 1216 A line--an assumption which is normally true for a hot filament-type hydrogen lamp. Subsequently, a Duoplasmatron light source was designed, built, and tested.

The principle of the Duoplasmatron can briefly be described as follows. A low pressure arc discharge in hydrogen, typically 20 to 100 microns pressure, is constricted by a funnel-shaped baffle placed between the electron emitting cathode (hot filament) and the anode. A strong axial magnetic field of approximately 2000 oersteds is developed between the baffle and the anode by a pole piece arrangement similar to those used as magnetic lenses in electron microscopes; this further constricts the discharge to a narrow plasma beam along the axis. If the anode has a central opening, a very intense ion or electron beam can be extracted from the plasma Any gas can be used to produce the ions provided the gas does not poison the filament.

II. DESIGN CONSIDERATIONS

In the Duoplasmatron the plasma density on the axis near the anode increases quickly with the magnetic field strength, and after passing a flat maximum slightly decreases. In practice, this means one has to operate the Duoplasmatron above a minimum magnetic field strength to provide a maximum plasma density on the axis. In conventional Duoplasmatrons the magnetic field is generated by a solenoid of 2000 to 7000 amp turns, providing a magnetic field of the order of 2000 oersteds between the pole pieces. However, it would appear that a permanent magnet of equivalent strength would be equally as efficient as a solenoid and at the same time have the following advantages: (a) no power supply for the magnetic field is needed; (b) since the heat generated in the solenoid is of the same order as the heat generated by the arc, then for a given cooling rate a higher arc current can be drawn if the solenoid is replaced by a permanent magnet; (c) since the baffle electrode, which forms one pole of the magnetic field, operates at a different electrical potential than the anode, which forms the other magnetic pole, it is necessary in the case of a solenoid to have an additional air gap in the path of the magnetic flux through the iron enclosure to provide electrical insulation. For a given magnetic field strength this requires additional magnetic induction. This is avoided if one chooses ceramic permanent magnetic material, which is electrically insulating. (d) There are ceramic magnets on the market which have an exceptionally high coercive force, typically around 2000 oersteds.[6] That means the required magnetic length is relatively small; therefore, less iron is needed and since the ceramic material itself is much lighter than copper, the whole assembly becomes considerably shorter and lighter than an equivalent design employing a magnet coil

III. CONSTRUCTION

A sectional view of the Duoplasmatron is shown in Figure 1. The magnetic field is provided by three rings of highly-oriented barium ferrite permanent magnetic material (Indox V) which are magnetized in the direction of their axis The magnetic flux goes from one pole of the magnet through the source flange and the slit holder over the gap, through the wall of the baffle electrode, and then through the cover plate to the other pole of the magnet The slit--the two halves of which are screwed to the slit holder--is held by the strong magnetic field between the apex of the baffle electrode and the slit holder which slides in the source flange This way the slit can easily be pulled out and inspected. The magnetic field presses the slit against the anode which is an air-cooled disc of copper The cooling disc, a ceramic spacer ring and the baffle electrode--onto which is screwed a stainless steel retainer ring--are sealed to the source flange with six screws simultaneously, having indium or gold O-rings between each other The baffle electrode is closed by a feed-through cap, which carries the gas inlet tube and two ceramic terminal bushings which hold two studs between which the filament is mounted. The filament is platinum mesh wire, which is dipped in a suspension of barium carbonate and activated in a hydrogen atmosphere A cooling fan, mounted on the cover plate, blows air through twelve holes in the cover plate, along the baffle electrode, through twelve holes in the cooling disc, and finally out through twelve channels in the source flange

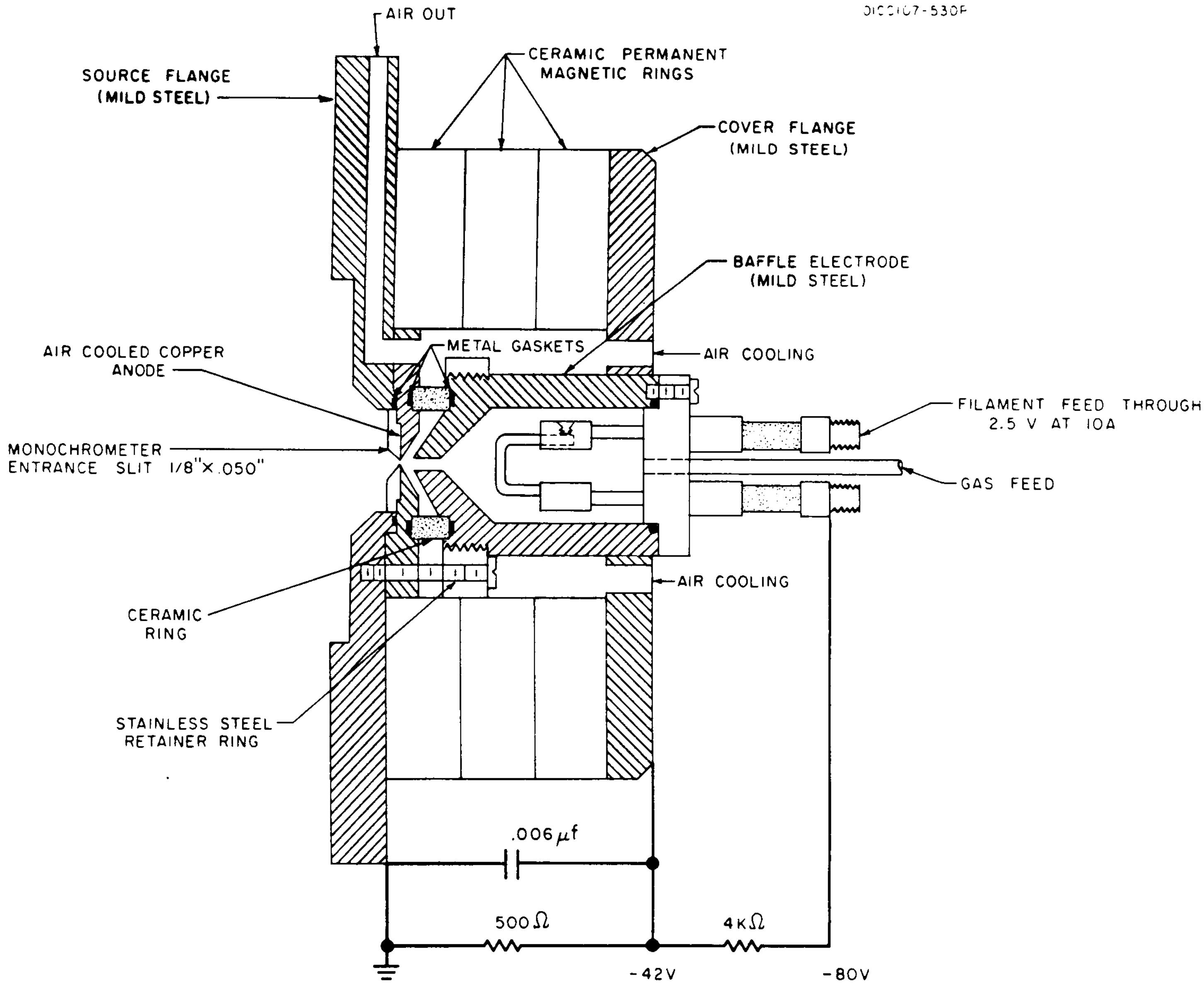


Figure 1. Duoplasmatron light source. The voltage distribution shown is typical under discharge conditions in hydrogen.

SCALE = 1in

The circuit diagram for the arc power supply is shown in Figure 2. The supply is current stabilized by simply inserting an amperite ballast tube in series with the load. Figure 3 shows the current-voltage characteristics of a typical tube. The power supply was constructed with ten amperite 3-38 A ballast tubes in parallel in order to provide current stabilization for 0 3 amps to 3 amps by switching in the number of tubes required to provide the desired arc current.

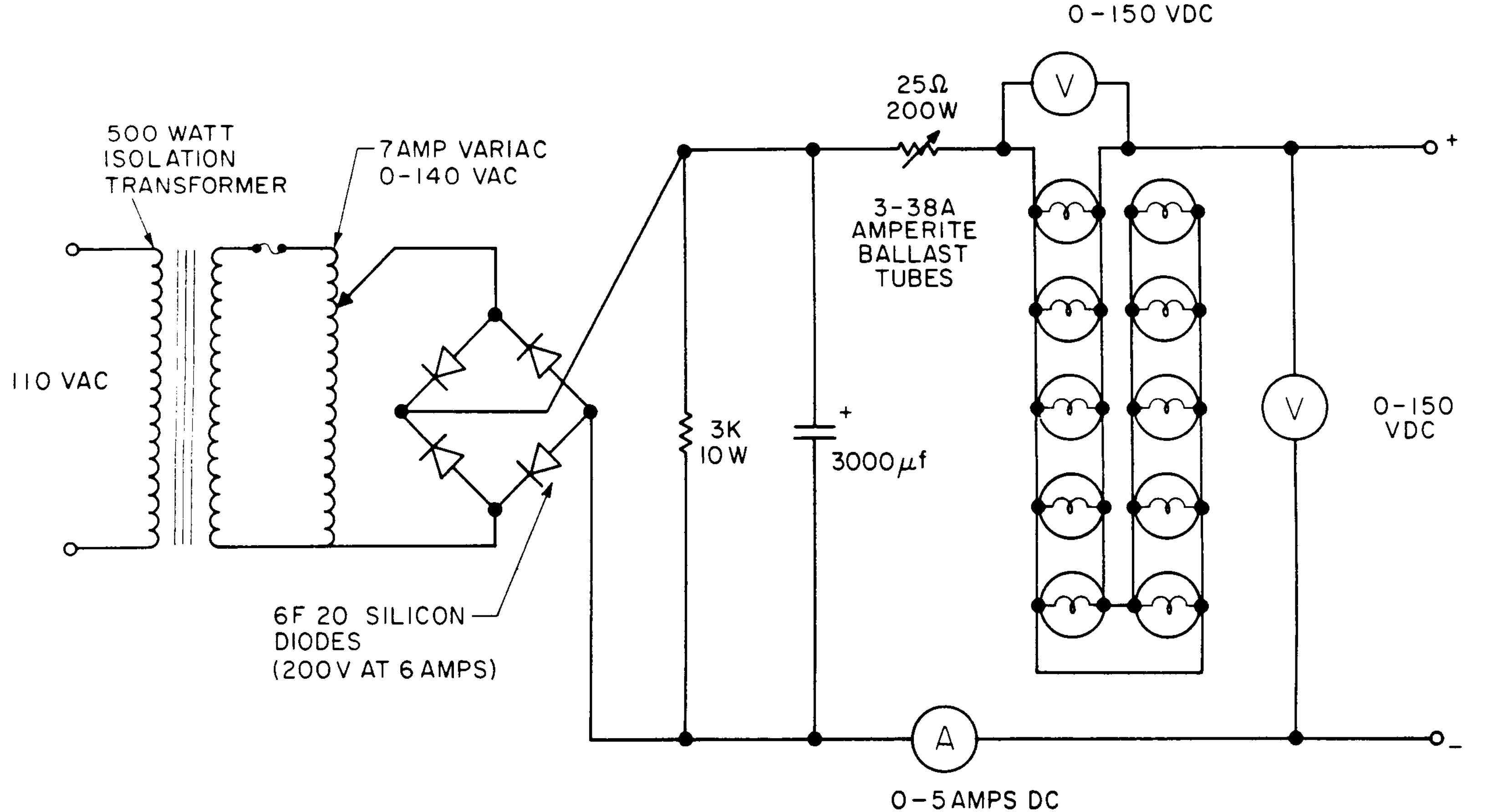


Figure 2. Current regulated power supply from 0.3 to 3 amps.

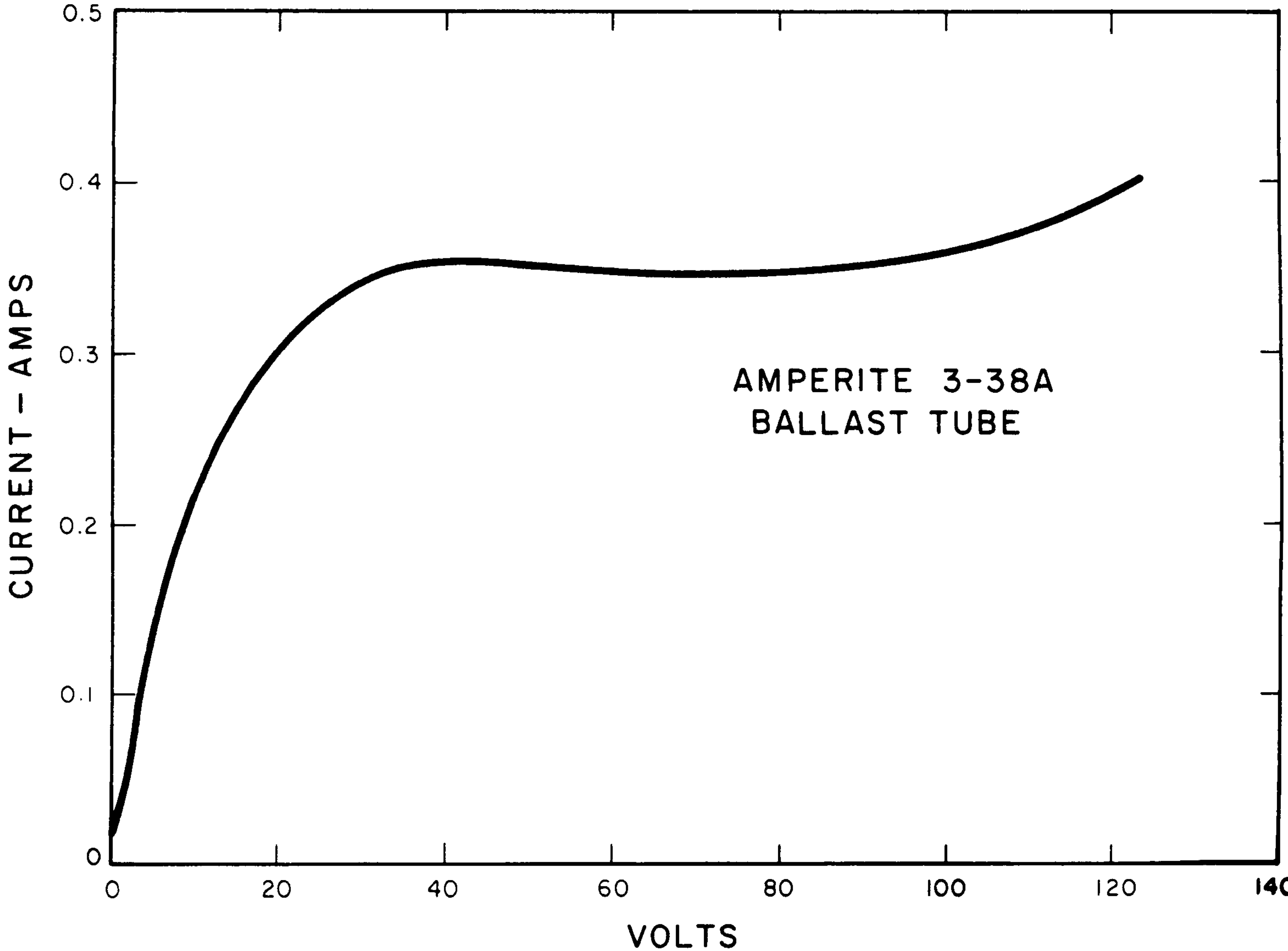


Figure 3. Current-voltage characteristic of an amperite 3-38A ballast tube.

IV. RESULTS

The Duoplasmatron, as shown in Figure 1, has been operated successfully both as an ion source and as a vacuum ultraviolet light source. The extractor aperture of the Duoplasmatron ion source was replaced by a slit assembly 1/8 inch high by 50 microns wide. The slit-assembly constituted the entrance slit of a 1/2 M Seya-type vacuum monochromator having a reciprocal dispersion of 16 A/mm. Under such conditions a wavelength resolution of approximately 2 A was obtained. No windows were used between the light source and the monochromator since no suitable materials exist which will transmit radiation below 1050 A (the short wavelength transmission limit of lithium fluoride). However, due to the low operating pressure of the Duoplasmatron and the small slit area, a pressure of 1×10^{-4} torr was maintained in the monochromator chamber without the use of a differential pumping chamber between the light source and monochromator. When the discharge was started, the pressure in the monochromator decreased by a factor of two or three. This, apparently, is due to the intense ionization in the vicinity of the entrance slit impeding the flow of neutral gas through the slit into the monochromator. The entrance slit is at a positive potential relative to the baffle in the Duoplasmatron.

The ultraviolet detector was an EMI 9514B photomultiplier tube sensitized to vacuum ultraviolet radiation by coating its envelope with sodium salicylate. The quantum efficiency of this scintillator has been measured from 2000 A down to 800 A and found to be constant [7]. Although it is probable that the constancy of the quantum yield of sodium salicylate continues in the region of our measurements down to 550 A, one must be careful in comparing the relative intensity of two lines rather widely separated as the efficiency of diffraction gratings in the vacuum ultra-violet region of the spectrum is not constant with wavelength [8].

Figure 4 shows the spectrum of hydrogen between 1800 A and 900 A. It is a typical hydrogen spectrum with the molecular continuum to longer wavelengths of 1650 A and the many-lined molecular spectrum to shorter wavelengths with the atomic lines of the Lyman series, alpha and beta, at 1215.7 A and 1025.7 A, respectively. However, it does differ from the spectrum produced in a hydrogen glow discharge (cold cathode type) in that the atomic resonance line at 1215.7 A is several times more intense than the most intense molecular line, usually 1608 A. As the arc current was varied from 0 to 0.9 amps, the light intensity increased almost linearly--the molecular lines increasing at a somewhat slower rate than the atomic lines. This result can be correlated with the analysis of the beam composition as a function of arc current as reported by Moak et al.[3] who found a rather linear and more rapid increase in the atomic ion content than in the molecular ion content.

An argon spectrum from 550 A to 1100 A is shown in Figure 5. The arc current was 1.5 amps with 30 volts between anode and filament. As the arc current increased from zero, the radiation from excited neutral

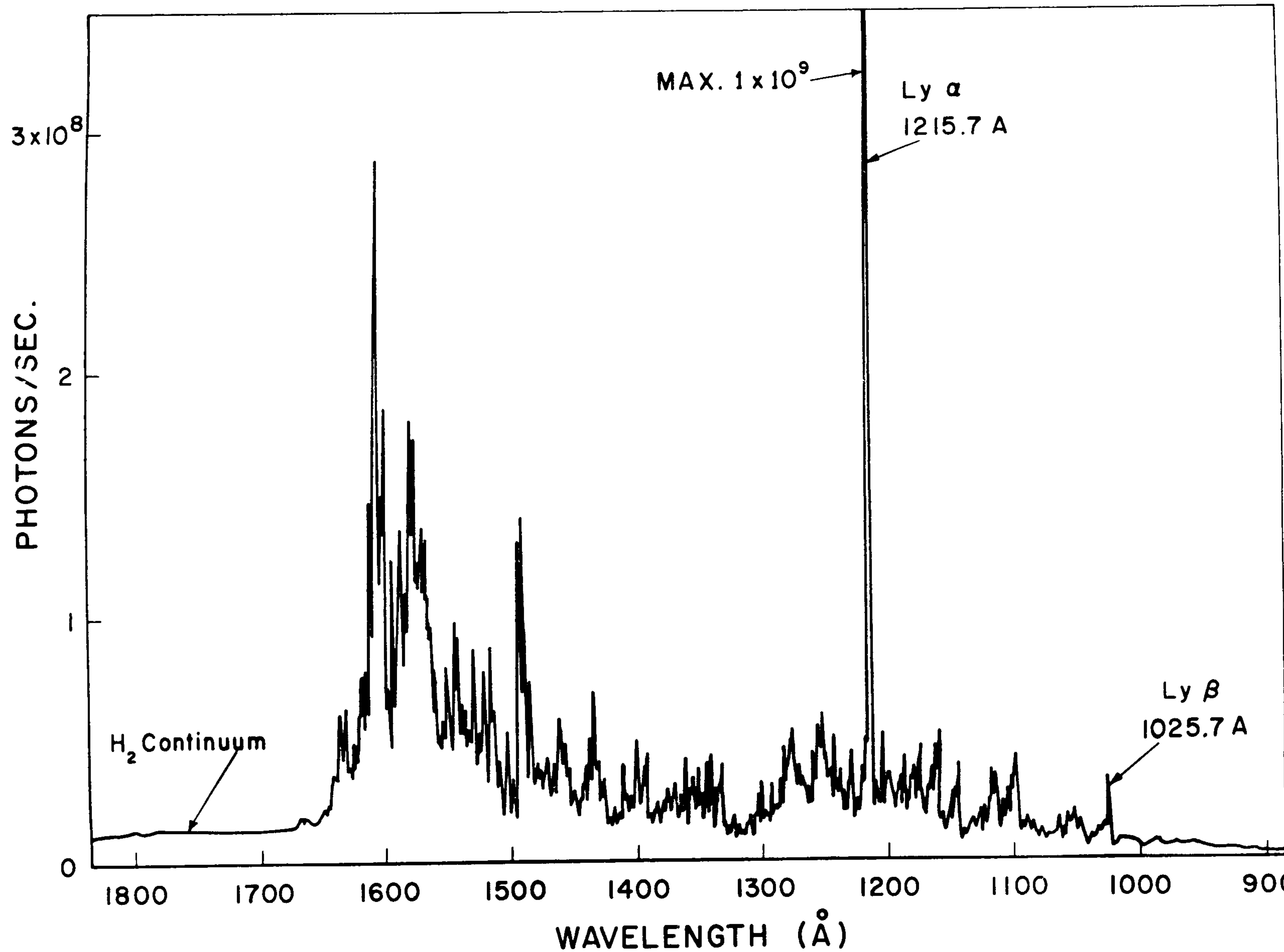
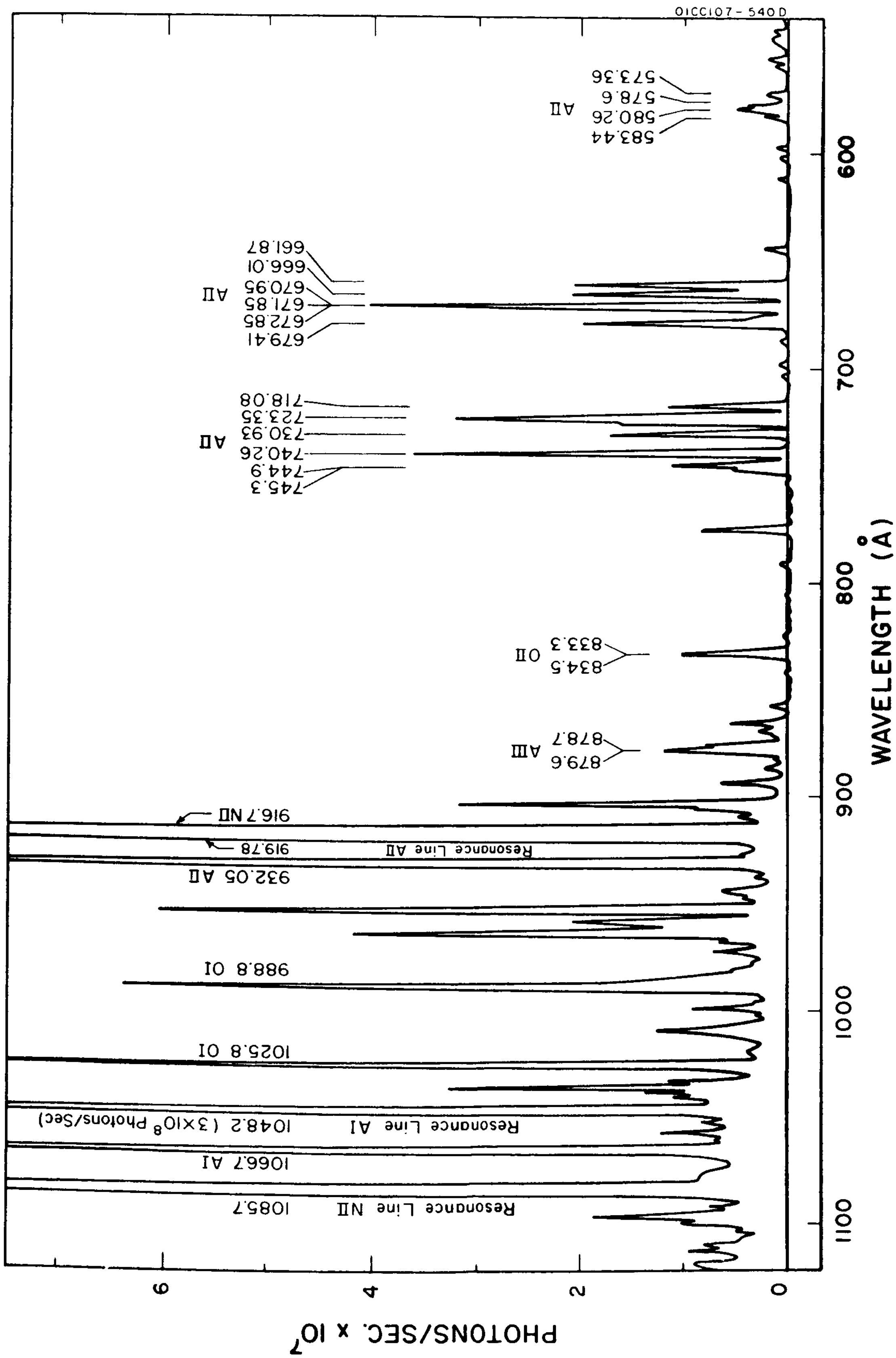


Figure 4. Hydrogen spectrum taken with an arc current of 0.9 amp. wavelength resolution is approximately 2 angstroms.



01CC107-540D
PHOTONS/SEC. x 10^7
0
2
4
6
WAVELENGTH (Å)
600
700
800
900
1000
1100
583.44
580.26
578.6
573.36
AII
679.41
672.85
671.85
670.95
666.01
661.87
AII
745.3
744.9
740.26
730.93
723.35
718.08
AII
834.5
833.3
OII
879.6
878.7
AIII
916.7 NII
919.78
Resonance Line AII
932.05 AII
988.8 OI
1025.8 OI
1048.2 (3×10^8 Photons/Sec)
Resonance Line AI
1066.7 AI
1085.7
Resonance Line NII

atoms increased to a maximum around 1 amp and then remained constant or even decreased slightly as the arc current increased further; however, the radiation from the singly and doubly ionized atoms continued to increase. At 3 amps the 879.6 A and 878.7 A lines of AIII were a factor of five more intense than shown in Figure 5, whereas the AII series increased by only a factor of two. The presence of an air leak was indicated by radiation from atomic nitrogen and oxygen.

That the magnetic field confines the discharge to a very intense radiating plasma along the axis is evidenced by the fact that if the ceramic magnets are removed one by one, the light intensity decreases rapidly to the point of essentially zero light intensity at zero magnetic field

The Duoplasmatron is suitable as a D.C. light source producing considerable intensity in the spectral region below 1000 A; however, the results presented here, in argon, are somewhat less intense than those of a 6 kv, 60 pps spark discharge. By increasing the arc discharge current, it appears possible to increase the intensity of the radiation to the point where it is comparable to that of the high voltage pulsed discharge

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